

Novel Applications of Pre- and Post- Consumer Carpet Wastes in Concrete

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ABSTRACT

On average a typical carpet manufacturing company in the UK produces between 15 to 20 tonnes of waste per week. This amounts to nearly £70 million of would be extra income per year. Post consumer carpet is difficult to quantify but the waste is likely to increase inline with other consumable practises. To alleviate the problem, a number of pioneering research initiatives have resulted in practical and potential solutions. However, by and large they are, as yet, not economically viable and could take a long time before they become universally acceptable. This work discusses some new initiatives which attempts to reduce costs by using suitably selected carpet wastes to reinforce concrete structures with potential benefits to both the concrete and carpet manufactures. Preliminary experimental results show improved fracture characteristics and effective containment of concrete segments after impact. Possible benefits of such systems other than dealing with carpet waste and concrete reinforcements will be discussed.

INTRODUCTION AND BACKGROUND

Carpet process and post consumer waste has become the subject of concern for many manufacturers and academic institutions around the world. The concept of "what to do with the waste" has consequently attracted huge funding and has now developed into a number of successful projects where, today, economic viability rather than technical feasibility is the main limiting factor affecting full scale implementation.

Environmentally unacceptable landfill dumping and incineration aside, the established methodologies include incineration with prime purpose of recovering the locked in energies which would in most cases equate if not exceed calorific outputs of normal fuel⁽¹⁾. Pyrolysis or burning in absence of oxygen is another process by which carpet waste is carbonized at high temperatures to generate synthetic coal. Other utilisation schemes have included shredding, granulation and mixing of the waste with binders to produce sheets or panels suitable for thermal and sound insulation materials in the building industry. Depolymerisation of constituent components to their parent monomer and subsequent re-polymerisation has kept many of the big players in the industry occupied for a long time resulting in many success stories. However the common denominator in each of these cases are the high costs associated to production, collection, separation, and cleaning depending on processing routes selected. Furthermore, disposal of ash or inorganic heavy metals and halogens as a bi-product of incineration could lead to further problems and where polymeric materials are regenerated, they could be subjected to sub-standard grading both in terms of technical applicability and market acceptability⁽²⁾.

Inclusion of virgin fibres into concrete for reinforcement has been known for sometime and is widely practised today. Many research publications from 1960s onward discuss

major improvements in fracture toughness, ductility and impact resistance⁽³⁾ of concrete containing steel, glass, carbon or synthetic fibres. Use of fibrous waste in composite settings with prime intention of reinforcement, however, is the most recent development where waste fibres through improved performance have enhanced waste fibre status to that of virgin materials. In a recent Ecotextile 98⁽⁴⁾ conference held at Bolton Institute, UK and the "3rd Annual conference on Recycling of Fibrous Textile and Carpet Waste"⁽⁵⁾, Georgia, USA, waste carpet fibres were particularly praised for their role in improving physical and in particular shrinkage cracking, toughness and durability of concrete. The research development site of Shaw Industries, Georgia, USA in which 20 tonnes of carpet waste fibres is claimed⁽⁶⁾ to have been used is currently "living" proof of successful application of such waste materials. Many more studies⁽⁷⁻⁸⁾ in the field where virgin or recycled fibres are used are geared towards similar objectives.

The work in this research focuses not so much on reinforcement of concrete in the conventional manner but on containment and control of concrete integrity after severe destabilisation has occurred. The need and usefulness of this study stems from post mortem examinations of earthquake-stricken buildings and/or after effects of bomb attacks or gas explosions that would usually cause structural damage beyond repair. The sudden impact of such tremors would normally split concrete into one or more pieces which could separate and conceivably fall out of place individually and/or promote further structural collapse (like a house of cards) causing injury or even death to the residing occupants.

Carpets by and large are made to last and have high tensile and mechanical properties. The notion of stripping carpets into individual components undermines the energies consumed during manufacturing and subsequent processes which must be added to the overall costs of recycling even when there are no collection and cleaning costs involved. It is in light of these concerns that the current work uses process and post consumer carpet wastes in their, almost, original state to achieve unique properties within concrete. In the proposed system, the carpet samples, under normal circumstances, reside passively in the concrete mixture and, ideally, would not interfere with the overall physical properties of the concrete. However, in the event of such extreme situations, as described above, become active by containing the damage and more importantly prevent total collapse.

Under compression or bending moments, concrete blocks fracture with brittle failure characteristics i.e. by clean, uninterrupted cracks and fracture planes occurring across or along the block. However, the presence of a viscoelastic material in the block, after such an event, could absorb some of the impact energy by virtue of its modest extensibility and high tensile strength (and hence work of rupture) thus maintain continuity within the separated portions. In a badly damaged building, the containment of otherwise separating pieces could be sufficient to prevent continued structural failure and hence total collapse of the structure under its own weight.

Inclusion of suitably selected waste carpets in the blocks would require no separation, cleaning or any of the costly processes associated with other methods of using waste thus embracing both the process and post consumer waste market.

EXPERIMENTAL

The preliminary experimental results presented in this report are part of a major programme of research currently in progress at Bolton Institute.

In carpet manufacturing, the largest quantity of waste both in terms of actual weight and costs occur at the final inspection stages where defects of one kind or another e.g. colour mismatch, stripes and streaks and so on could lead to direct disposal. The subsequent fittings and the cut to size practice adds a further element of waste that could be as high as 20%⁽²⁾. It is these kind of waste that have been the prime target of this work. In fact the first series of experiments have included; reject, tufted nylon tiles with PVC backing supplied by Milliken, UK. The tiles were cut to shape using one of a range (i.e. 1a) of possible templates shown in figure 1 with no further treatment.

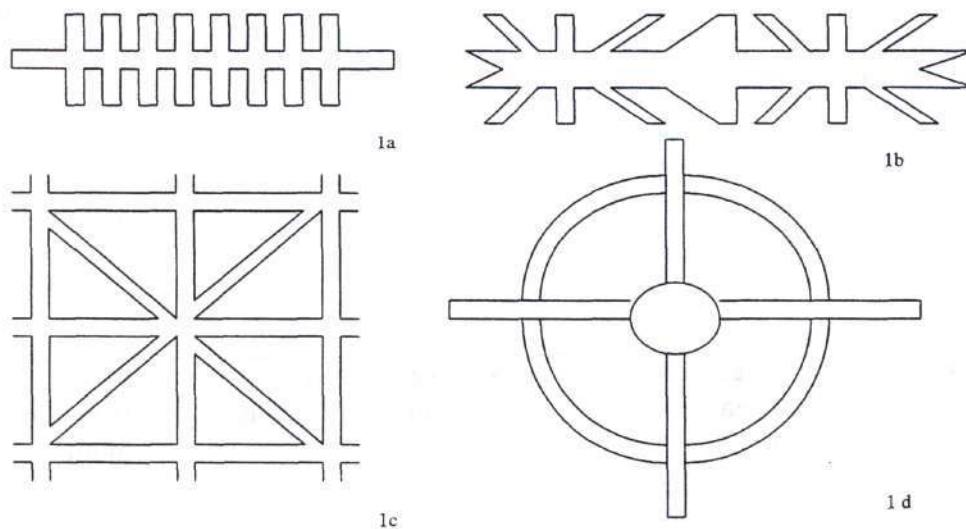


Figure 1

The cut out samples were initially tensile tested in both machine and across machine direction and concrete mixture was prepared using the formulation given below and turned in a drum mixer to ensure uniform consistency.

15 kg	Course aggregate (crushed limestone)
7.5 kg	Fine aggregate (dredged river sand)
5.25 kg	Ordinary Portland cement
2.62	Litres of water

The moulds measuring 500mm by 100mmX100mm were treated with a releasing agent (i.e. diesel based oil) prior to receiving the concrete mix. The carpet samples were inserted in the

moulds in the configuration shown below and placed on a vibrating table for 10-15 seconds to extract trapped air and allow effective compaction..

Samples
Plain concrete
1 horizontal layer placed half way through the concrete mix.
1 vertical layer inserted in the middle of the concrete mix.
2 horizontal layers placed 1/3 rd and 2/3 rd of the way in the mould.
3 dimensional insert placed in the middle of the concrete mix.

The moulds were kept in the laboratory for 24 hours under room condition before stripping. The blocks were subsequently placed in a water tank at 22°C for 28 days to allow curing.

The testing protocol included a standard four-point flexural test followed by residual strength assessment of the separated piece whilst still attached by the carpet yarns. This was followed by an improvised impact resistance test.

RESULTS

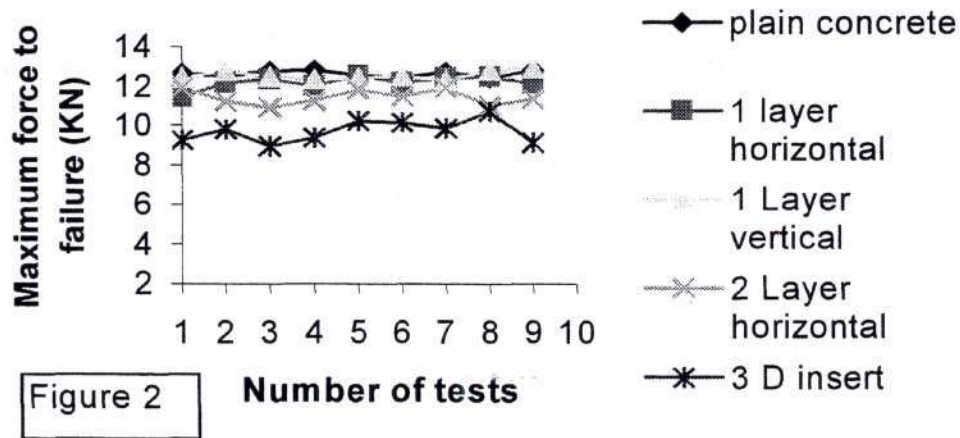
Tensile test results of the carpet samples, in machine and across machine direction are given in table 1.

Table 1

Samples	Average Breaking Load (N)	Standard Deviation	Average Breaking Elongation (%)	Standard Deviation (mm)
Along machine dir.	0.5202	0.0076	2.2	0.092
Across machine dir.	0.4651	0.0190	2.62	0.127

The relatively low values for both maximum breaking load and elongation relate to the PVC backing that fail long before the pile yarns which maintain continuity beyond initial recorded failure. However, pile yarns tested separately register-breaking loads of up to 54N and 43% breaking strain.

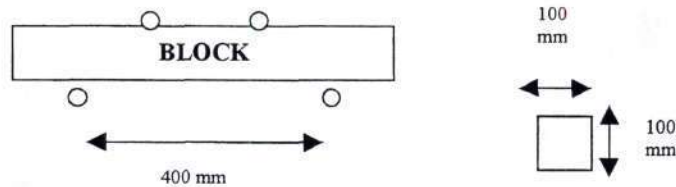
The four-point flexural test results are presented in figure 2 below.



The plot shows maximum breaking load values in kN against number of tests carried out. Using this data, average maximum stress values can be determined by the following equation.

$$\sigma = \frac{\text{Maximum load} \times \text{Block span length (i.e. 0.4m)}}{\text{Block width (i.e. 0.1)} \times \text{Block height}^2 \text{ (i.e. 0.01)}}$$

Where

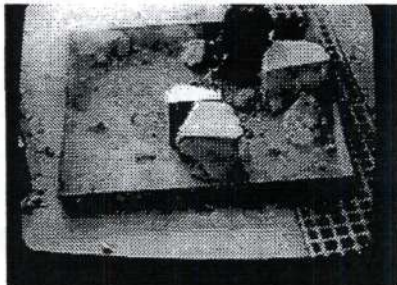


Hence;

Samples	Average Maximum Breaking Load (kN)	Average Maximum Stress or σ (MPa)
Plain	12.76	5.10
1 layer horizontal	12.40	4.96
1 layer vertical	12.78	5.11
2 layer horizontal	11.95	4.78
3D insert	10.504	4.20

The plain concrete, following normal fracture mechanics, splits into two parts under the four-point flexural test whilst tolerating an average maximum stress of upto 5.10 Mpa, where as samples with viscoelastic carpet inserts remain partially attached after the test. More interestingly however, the average tolerable stress prior to failure for one layer inserts are 4.96 and 5.11Mpa thus suggesting little or no loss in overall maximum stress between the plain concrete and those with 1 layer inserts. Increasing the layers to two and beyond results in reduced average maximum stress. Simple attempts to evaluate the maximum tolerable stress prior to final detachment have not been entirely satisfactory but vertical loading of up to 250 N has shown no sign of pile yarn failure. The main body or backbone of the carpet inserts consists of continuous pile yarns which on average accommodate 10 rows of pile yarn summing up to minimum breaking load of 540N. Furthermore, when stress tolerance rises the subsequent pile yarns (still in the concrete) pull out of position intermittently to relieve excess load.

To assess the effect of sudden impact, a sledgehammer was used to strike the blocks in two or three blows. The plain concrete, under these conditions, shattered into pieces throwing debris into and beyond the testing vicinity. Blocks containing the carpets however, broke into small segments whilst remaining attached, as an integral part of the block. Both the main core and the wings of the carpet inlays firmly held on to broken segments. Similar results were recorded for all the carpet insert configurations. Pictures below show comparative strike aftermath of blocks with and without the carpet waste insert.



Shattered pieces of concrete block with no carpet waste insert.

Shattered pieces firmly held together by the carpet waste insert.



DISCUSSION AND CONCLUSION

Preliminary test results indicate that inclusion of selected carpet waste samples into standard concrete blocks, within limits, does not impede the normal functional behaviour of these blocks. Under normal application conditions, the carpet inserts serve no purpose other than hiding away the waste that would possibly end up in landfills. However, since most carpets are made from nylon or polypropylene with PVC or styrene-butadiene latex rubber (SBR)

backing, they are not attacked by the alkalinity of the concrete mix⁽⁹⁾ and remain largely inert, thus maintaining much of their original properties. In an event of an explosion, earthquake or other similar phenomena the carpet would be prompted into action and as preliminary examinations show prevent concrete dislocation and hence further damage. The possibility of retaining the shattered pieces intact could indeed be instrumental in preventing total structural collapse and hence saving lives.

The main programme of study born out of these early results is currently focused on the following objectives:

- a) to identify most suitable carpet inserts in terms of required property and functional geometry.;
- b) to establish optimum concrete mix characteristics whilst in company of carpet inserts to achieve comparable properties to plain concrete when used in conventional manner.;
- c) to enclose post-consumer carpet waste in the identified form to confirm their suitability.;
- d) to carry out a range of standard laboratory tests on blocks containing the carpet wastes.;
- e) to build laboratory-sized structures using the optimised configurations and carry out controlled explosions ; and
- f) to asses, evaluate and finalise their applicability.

Successful completion of this work is anticipated to benefit the construction industry by reducing the quantity of normal concrete mix per mould/square meter and hence the overall costs. The impact containment or in built safety aspect of the blocks could revive and start off a whole new generation of construction products with huge financial benefits within UK and overseas.

The carpet industry will also benefit by being able to sell their otherwise unwanted waste at a premium price and make further savings by avoiding removal costs and landfill charges. Any reduction in carpet waste dumping (pre or post consumed) will be a move in favour of EU, national and local authority recycling and waste minimisation targets and hence a step towards creation of better environment within towns and cities.

Unlike many methods of recycling and reuse of carpet waste, where the problem of waste is effectively delayed, the final product emerging from this study will offer a realistic and economic solution for vast quantities of carpet wastes. Furthermore, since buildings are usually built to last for a considerable time (eg. 50 years or more), inclusion of carpet waste in concrete blocks or slabs, even in absence of such sudden releases of energy, will practically serve as a "permanent" resting place for the waste.

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Bio-sketch

Dr Mohsen Miraftab, graduated from University of Manchester Institute of Technology (UMIST) in 1986 with Ph.D. in fibre science. The following three and half years were spent at Reading University working as a post-doctorate on an ICI sponsored project. From 1990 to present time has been employed by Bolton Institute as a lecturer/senior lecturer and researcher. Current interests are in recycling, geo-and medical textiles.